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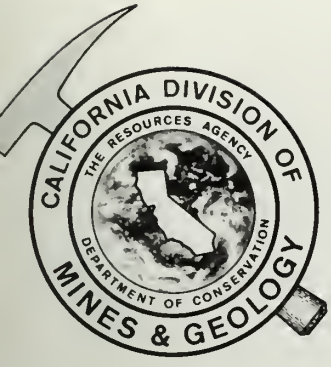

SPECIAL PUBLICATION 57

PROPOSED EARTHQUAKE SAFETY PROGRAMS AND ACTIVITIES OF THE DEPARTMENT OF CONSERVATION FISCAL YEARS 1982 THROUGH 1986

1980

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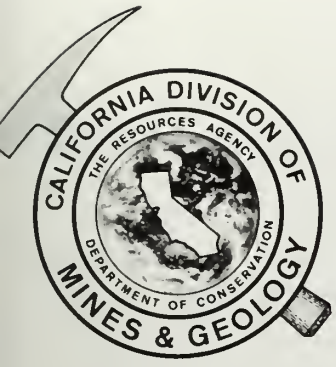

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PREFACE

The projects presented herein as program opportunities for the five-year period July 1, 1981, through June 30, 1986, have been developed by the California Division of Mines and Geology (CDMG) with attention to the priorities of public safety, the role of the CDMG within the Department of Conservation and within state government, and the expertise and experience of the CDMG staff. The CDMG emphasizes field work and areal observations that bear directly upon the needs of local and state government for public safety policy formulation, and leaves theoretical, pure research to the University where it rightfully belongs. Detailed site-specific investigations are generally within the purview of the consulting community, which provides direct advice to its clients.

In setting forth these proposed activities for the coming five-year period, the CDMG has extended some of its current activities into the future. Also, some new activities are proposed which are logical additions, both in terms of public safety needs and in terms of the capability of the CDMG to execute these projects, using its greatest staff strengths in geologic hazards analysis.

The primary consideration used in formulating and selecting the projects proposed in this report was the project's value for earthquake hazard reduction in California. Budgetary constraints were set aside, although it is clear that before these projects can be implemented the problem of funding will have to be solved. As in the past, this may require a combination of federal, state, and local funding.

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REPORT SUMMARY

Purpose and Scope of Report

This report has been prepared pursuant to Interagency Agreement SS-12, dated June 5, 1979, between the Seismic Safety Commission and the Department of Conservation for the purpose of providing the Commission with information concerning all the programs and activities related to earthquake safety that the Department believes it should undertake over the next five years. The interagency agreement calls for the Department to suspend budgetary considerations in developing its earthquake safety project proposals.

The report describes programs and activities which are within the Department of Conservation's legislative mandate (Chapter 2 of Division 1 and Chapters 1 and 2 of Division 2 of the Public Resources Code) and which should be continued, expanded, or initiated during fiscal years 1981-82 through 1985-86. The proposals are recommendations either for the expansion of existing projects or for the institution of new ones. Increased funding would be required to implement the proposals. In this summary and throughout the report, proposals are highlighted with a bullet sign (•).

Role of the Department of Conservation in Earthquake Hazard Reduction

The Department of Conservation contains the principal operational earth science agency in state government - the California Division of Mines and Geology (CDMG). The CDMG is the state geological survey for California. As such, one of its principal objectives is to identify geologic and seismic hazards and their underlying causative mechanisms in order to provide information to improve public safety and to reduce property loss by enabling more prudent land use decisions.

Earthquake Safety Project Proposals

During fiscal years 1980-81 through 1985-86 the California Division of Mines and Geology (beyond maintaining on-going programs) should:

•Accelerate work on the new regional 1^{o} X 2^{o} (latitude, longitude) quadrangle map series, scale 1:250,000, to allow the completion of at least two quadrangles (rather than the currently projected one) each year. This should enable the project to be completed in about 15 years. If the Department's budget change proposal (for fiscal year 1980-81) to accelerate geologic mapping is approved, the data base from which the compilations are made will be greatly improved and the quadrangle production rate will be slightly increased.

•Expand detailed mapping of fault zones in urban and urbanizing areas of the state. The fault maps, generally prepared at scales larger than 1:62,500, have a wide spectrum of users including local government planning and engineering staffs as well as CDMG staff. These maps are especially useful for evaluating the seismic safety of particular development proposals.

•Initiate a special study of the west side of the Central Valley of California from the vicinity of Kettleman Hills north to the vicinity of Lake Berryessa to determine whether a specific fault mapping project should be conducted there. This area has been the location of four magnitude 6 to 7 earthquakes in the past century and three magnitude 5.5 to 6 earthquakes in the present century. If a major fault exists in this area capable of generating a significant earthquake, it could represent the single most significant source of seismic hazard for the entire Great Valley.

•Prepare a series of summary articles or data sheets on typical fault ruptures based upon fault evaluation studies. The purpose would be to systematically characterize different types of surface fault rupture for different types and magnitude of faulting in different terrane.

•Prepare a manual on the use of geomorphic features in characterizing the age of latest movement of faults; the manual would be used in evaluating potentially active faults for the Alquist-Priolo Special Studies Zones Act program.

•Initiate a study to analyze the spacial and temporal variations of the data in the CDMG Earthquake Catalog for use in seismic risk studies.

•Restudy the locations of selected groups of critical earthquakes in the CDMG Earthquake Catalog using modern, precisely located earthquakes in the master event location technique.

•Standardize the quality ratings assigned to the earthquake locations in the CDMG Earthquake Catalog.

•Increase the number of trained personnel to carry out the seismic monitoring of aftershocks following selected significant earthquakes and other seismic monitoring projects.

•Expand studies to evaluate possible reservoir-induced seismicity.

•Expand studies of recency and recurrence of faulting. These studies should include detailed geologic mapping, trenching and borehole sampling, and the application of various age-dating techniques such as radioactive dating, soils analyses, and geomorphological studies. Geodetic monitoring should be conducted on those faults that have been identified as "seismically active" in order to identify slip rates and type of movement occurring.

•Initiate a study to assess the applicability of various age-dating techniques to age-date Quaternary and Holocene sediments.

•Initiate a study to evaluate the concept of maximum expectable earthquake magnitude, the methods used to determine it, and its proper application for use in the evaluation of seismic risk at locations where sensitive manmade structures are planned.

•Initiate a special program to analyze and model the sequential changes in the stress field due to successive magnitude 6 and larger earthquakes occurring on known faults in the San Francisco Bay Area during historic time.

•Initiate a study to analyze the CDMG strong-motion records to determine earthquake source parameters such as fault dimension, slip, and stress drop.

•Initiate a study to develop the capability to model the interaction of earthquake waves and the transmitting media.

•Initiate studies of urban areas of the state that are underlain by thick sections of Quaternary sediments using the technology developed in the current CDMG Orange County ground response study.

•Accelerate instrument deployment for the Strong Motion Instrumentation Program (SMIP) the maximum amount consistent with efficient operation in order to reduce the time required for instrument installation from 40 years to 10 years and greatly enhance the CDMG seismologic contribution to seismic risk mitigation studies.

•Improve the SMIP electronics laboratory to provide for instrumentation improvement to meet the state's unique needs.

•Expand its capability to conduct studies of secondary failures, mainly landslides, following damaging earthquakes.

•Initiate a program to evaluate the potential risk of seismically triggered landslides occurring in urban and urbanizing areas.

•Initiate a study to analyze the geometry of fault ruptures and to correlate these with type of faulting and size of earthquake. The resulting correlations may be useful for estimating fault rupture patterns for future earthquakes.

•Expand the monitoring of telluric current and microacoustic emissions along the Parkfield-California Valley segment of the San Andreas fault in order to evaluate the effectiveness of these monitoring techniques for earthquake prediction..

•Expand public education efforts (1) by regularly releasing news stories on the work of the CDMG in the areas of earthquake investigation and seismic safety; (2) by using television and radio spot announcements to broaden distribution of CDMG seismic safety information; (3) by providing CDMG staff to give talks on seismic safety at schools,

colleges, and universities on request; and (4) by making taped lectures and slide shows on seismic safety subjects available to public groups free of charge.

•Evaluate the feasibility of establishing a library of unpublished, geotechnical data.

•Evaluate the effectiveness of the detailed fault rupture maps the CDMG produced after the 1971 San Fernando earthquake.

•Initiate a program to review and evaluate the effectiveness of the seismic safety elements of general plans of all local governments.

•Initiate a program to review the geology and seismology of all facilities that store or produce substantial amounts of radioactive material and to identify facilities that pose potentially significant environmental and public health hazards in the event of seismic damage.

•Initiate a program to review the geology and seismology of oil, gasoline, and natural gas pipelines that are in highly populated areas of the state to identify seismic hazards that might exist.

•Initiate a study to determine whether or not a seismically safe site for the disposal of radioactive wastes exists in California.

Role of the Department of Conservation in Earthquake Hazard Reduction

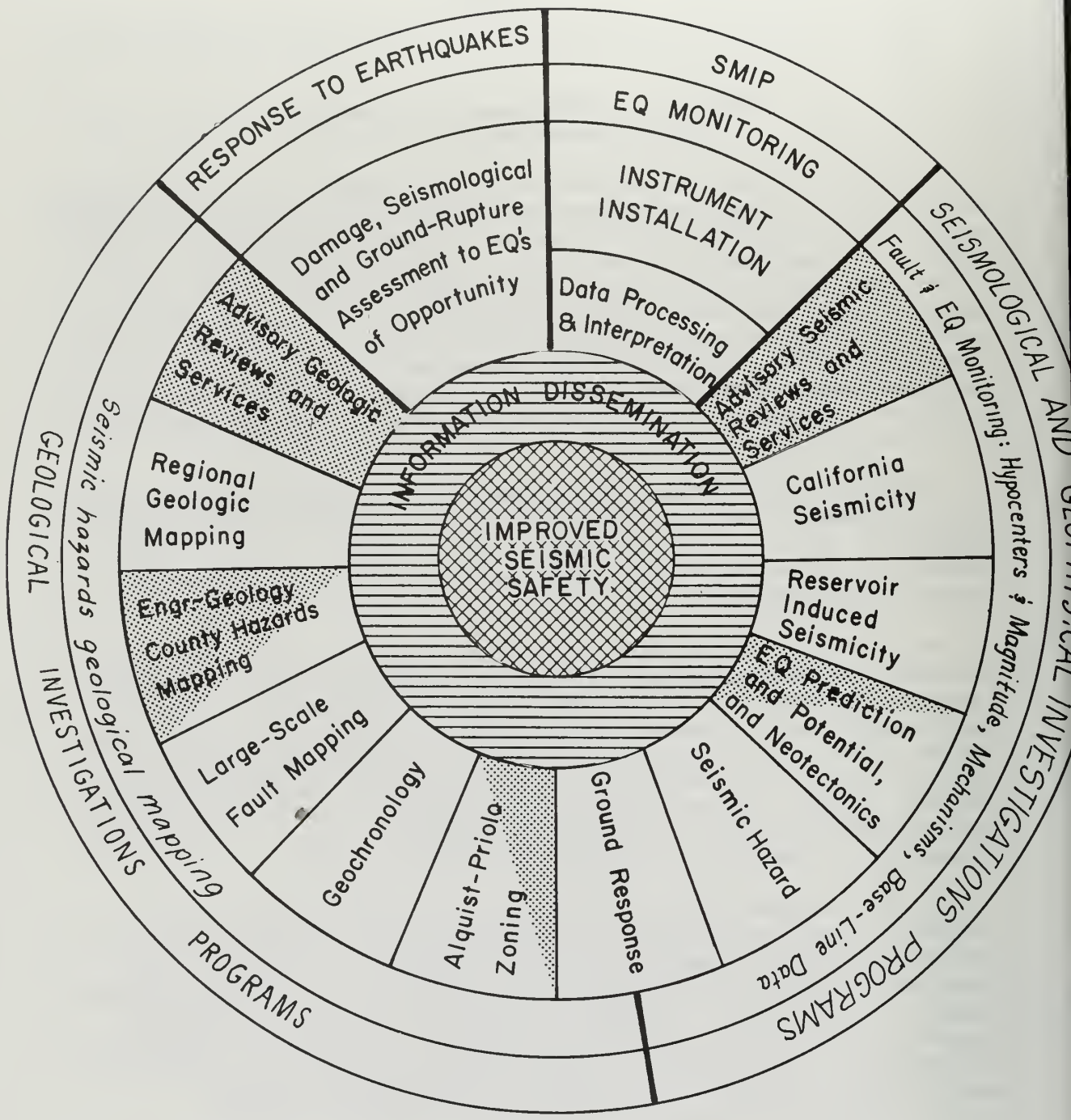
The odds are even that a great earthquake (magnitude ≥ 7) will strike California by the year 1990 (Bolt and Jahns, 1979, p. 9) and cause 10,000 deaths and 10 billion dollars in property damage (Steinbrugge and others, 1978, p. 7). Statements of this kind, made by highly regarded authorities, are being heard with increasing frequency. After every moderate earthquake (magnitude $\geq 5 < 7$) in California, of which there are about six a year on the average (Real and others, 1978), warnings of the great earthquake are repeated. The Department of Conservation is convinced that these warnings are not exaggerated. A great earthquake will come. The death and destruction following it will be devastating unless more is done to improve the seismic safety of California.

The Department of Conservation, one of several agencies concerned with earthquake hazard reduction in California, contains the principal operational earth science agency in state government - the California Division of Mines and Geology (CDMG). CDMG serves as the geological survey for California.

One of the principal objectives of the Department of Conservation is the identification of geologic and seismic hazards and their underlying causative mechanisms in order both to provide information to improve public safety and to reduce property loss by enabling more prudent land use decisions. This objective is carried out within the Department's Geologic Hazards and Mineral Resources Conservation Program, conducted by the CDMG (1979). The earthquake hazards reduction work of the CDMG is accomplished through two major program elements: Land Use Geology, and Seismology and Geologic Information and Publications.

These earthquake hazard reduction functions of the CDMG, their interrelations, and the types of information activities they involve are illustrated by the seismic safety wheel (Figure 1). The goal of all these activities is improved seismic safety, which is represented as the inner hub of the wheel. The four information-acquisition activities represented as the outer rim of the wheel are: response to earthquakes; the California Strong Motion Instrumentation Program (SMIP), which monitors characteristics of earthquake-induced ground shaking; seismological and geophysical investigations; and geological investigations.

CDMG's program of immediate, active response to earthquakes of opportunity permits analytical studies of fault-generating mechanisms, surface rupture, and ground response - studies which provide new insights to be employed in mitigating the dangerous and destructive effects of future earthquakes. The Strong Motion Instrumentation Program was instituted after the damaging San Fernando earthquake of February 9, 1971, for the purpose of improving understanding of ground shaking and



CDMG SEISMIC SAFETY WHEEL

Figure 1

its effects upon man-made structures. The program involves the maintenance of a sophisticated network of specialized instruments to record and analyze earthquake shaking effects.

A variety of seismological and geological investigations are enumerated as spokes of the seismic safety wheel. The distinction between those designated as seismological and geophysical information acquisition studies, and those designated as geological programs is somewhat arbitrary. Information and interpretive insights derived from each of these related disciplines are provided by the CDMG to appropriate parties through its direct Advisory Services activities, its earthquake prediction evaluation activities, and its activities under the Alquist-Priolo Act, which mandates the establishment of Special Study Zones (within which constraints on land use obtain) in the proximity of active surface faults.

The ultimate beneficiaries of CDMG earthquake hazards information are the people of California, but it is through the activities of the principal users of this information that the benefits are realized. These principal users are:

- Structural Designers, Engineers (public and private)
- Local Government Land Use Regulators, Building Code Enforcers, and Planners
- State and Regional Regulators
  - California Energy Commission
  - California Coastal Commission
  - Public Utilities Commission
  - Office of State Architect
  - Department of Water Resources
- State Office of Planning and Research
- State Office of Emergency Services
- California Seismic Safety Commission
- California Department of Transportation
- Federal Agencies
  - Nuclear Regulatory Commission
  - National Bureau of Standards
  - U.S. Geological Survey
  - U.S. Army Corps of Engineers
  - U.S. Water and Power Resources Services
- Power and Utility Companies

Generally, the public agencies listed here are charged with providing either the planning for or the regulation of decisions which impact upon public safety. To state and regional regulators, CDMG Advisory Services provide advice and information related to the geologic and seismic design requirements of power plants, liquefied natural gas facilities, hospitals, and dams. The Office of Emergency Services, which has particular responsibility for organizing and coordinating earthquake response planning, must anticipate potential earthquake damage in urban areas and develop strategies to cope with these projected outcomes. The State Geologist, Chief of the CDMG, assists in the performance of these

responsibilities in his role as chairman of the California Earthquake Prediction Evaluation Council, which meets under the auspices of the Office of Emergency Services. Advice to the Seismic Safety Commission includes technical input for the development of legislation.

Information dissemination, represented on the seismic safety wheel as the inner rim, is a crucial function in CDMG's earthquake hazard reduction activities. Too often this function is slighted by scientists, who traditionally prefer that some other party accomplish this type of information transfer for them. Clearly the best way to assure the practical application of technical insights to public safety is to deliver those insights successfully to information users. Thus the primary purpose of the CDMG is to provide the best geotechnical insights and information available to public decision-makers at all levels.

Purpose and Scope of Report

This report has been prepared pursuant to Interagency Agreement SS-12, dated June 5, 1979, between the Seismic Safety Commission and the Department of Conservation. Interagency Agreement SS-12 was developed in response to SB 1279 (Alquist), which requires the Seismic Safety Commission to undertake a study of earthquake hazard reduction and earthquake prediction in coordination with specified state agencies.

The purpose of the report, as specified in the agreement, is to provide the Commission with information concerning all programs and activities related to earthquake safety that the Department believes it should undertake over the next five years, assuming no budget limitations. The report describes programs and activities that are within the Department of Conservation's mandate and that should be continued or developed and implemented during fiscal years 1981-82 through 1985-86. The report outlines accomplishments within existing programs, recommended areas of expansion, new programs and activities that should be implemented, and possible functions that may need additional study before specific new programs can be formulated.

The projects presented herein as program opportunities for the five-year period have been developed by the California Division of Mines and Geology (CDMG) with attention to the priorities of public safety, the role of CDMG within the Department of Conservation and within State government, and the expertise and staff experience of CDMG. The CDMG emphazes field work and areal observations that bear directly upon the needs of local and state government for public safety policy formulation, and leaves theoretical, pure research to the University where it rightfully belongs. Detailed site-specific investigations are generally within the purview of the consulting community, which provides direct advice to its clients.

The primary criterion used in formulating and selecting the projects proposed in this report was the project's value for earthquake hazard reduction in California. Budgetary constraints were set aside, although it is clear that before these projects can be implemented the problem of funding will have to be solved. As in the past, this may require a combination of federal, state, and local funding.

It is hoped that this discussion will assist the Seismic Safety Commission in its continuing coordination and development of public safety.

Throughout this report, project proposals are highlighted with a bullet sign (•).

Legislative Mandates under which Division of Mines and Geology Operates

The legislative mandates under which the Division of Mines and Geology operates are set forth in Chapter 2 of Division 1 and Chapters 1 and 2 of Division 2 of the Public Resources Code. The sections relevant to earthquake hazard reduction and prediction are summarized here.

Sections	Substance of Law
601, 607	Established Department of Conservation in The Resources Agency and Division of Mines and Geology and three other Divisions in Department of Conservation.
608	Established State Geologist as Chief of Division of Mines and Geology.
2201	State Geologist shall employ geologists and qualified specialists to do Division's work.
2203	State Geologist shall submit an annual report, including review of measures taken to counter geologic hazards.
2205	State Geologist may: Conduct studies of geologic hazards in urban areas, including activities under cooperative agreements; issue reports and maps on the geology of the State.
2622	State Geologist shall delineate Special Studies Zones to encompass potentially and recently active faults (Alquist-Priolo Act).
2700	State Geologist shall conduct the Strong Motion Instrumentation Program throughout the State.

In addition to the mandates in the Public Resources Code, the Division of Mines and Geology is authorized to conduct geologic hazards studies by annual budgets approved by the legislature. These studies are contained within the Geologic Hazards and Mineral Resources Conservation Program of the Department of Conservation.

IDENTIFICATION, DELINEATION, AND EVALUATION OF EARTHQUAKE-GENERATING POTENTIAL OF FAULTS

The California Division of Mines and Geology locates and investigates earthquake-generating faults. These activities include identifying and delineating faults, determining the maximum size of earthquakes that specific faults can generate, determining the frequency of occurrence of earthquakes on specific faults, and studying earthquake mechanisms. It is a state responsibility to identify and evaluate major fault zones and areas of earthquake hazard, and to prepare guidelines for land use regulation and construction in the zones (Scott, 1979, p. 19).

Fault Mapping and Analysis

There are two basic categories of fault mapping - regional fault mapping and detailed fault mapping. Regional fault mapping is generally conducted at scales between 1:1,000,000 and 1:100,000; detailed fault mapping is generally conducted at scales of 1:62,500 to 1:24,000.

The compilation and publication of regional geologic and fault maps are traditional tasks carried on by state geological surveys. Compilation of these maps involves synthesizing available geologic and fault mapping into regional or statewide small scale maps. The CDMG has been responsible for this program in California since the 1930s.

These regional maps are compilations of the more detailed mapping that has been done at larger scales. The process of compilation provides an opportunity to identify gaps in understanding which, once identified, pose new questions to be answered. A budget change proposal currently before the legislature would accelerate the production of detailed geologic mapping in the state. Field support funds would be provided to qualified graduate students and others to conduct new mapping projects in critical areas of the state. These areas will be identified through the compilation process and will be based on projected needs where current geologic information is inadequate by today's standards or is nonexistent. Large regions of California have been mapped only in reconnaissance fashion. In other large areas the most recent geologic information is almost a century old. Since the compilations can only be as good as the mapping on which they are based, this inadequate data base must be modernized to reflect new geologic understanding and increase the utility of the compiled maps. The maps are useful for making regionalland use plans, in locating and planning large-scale civil engineering projects, and in teaching or studying geology and geophysics.

There is a wide spectrum of users for these maps, ranging from earth science specialists to the interested general public, and including all levels of government as well as the private sector. The CDMG 1:750,000 scale Geologic Data Map Number 1, Fault Map of California, and the 1:250,000 scale Geologic Atlas of California sheets have proved to be popular with both professional users and the general public.

•A new regional 1^{o} x 2^{o} (longitude, latitude) quadrangle map series, scale 1:250,000, was initiated during fiscal year 1978-79. The Sacramento Quadrangle, the first of the new series, is scheduled for publication during fiscal year 1980-81. At the present rate of progress, five quadrangles will be completed in the next five years leaving 21 other quadrangles in need of compilation. If the budget change proposal to accelerate geologic mapping is approved, the data base from which the compilations are made will be greatly improved, and the quadrangle production rate will be slightly increased.

We hope to expand work on this new edition of the 1^{o} x 2^{o} quadrangle map series to allow the completion of at least two quadrangles each year. This should enable the project to be completed in about 15 years. The usefulness of these maps depends to a large extent on the timeliness of the information depicted on them. Development of useful regional maps is essential to CDMG's continued performance as a first-rate state geological survey.

In recent years, detailed fault mapping projects have been conducted largely in cooperation with local governments or with the U.S. Geological Survey. They are commonly prepared at scales of 1:6,000 to 1:12,000 and are later published at scales ranging from 1:12,000 to 1:48,000. The principal users of the detailed maps are the planning and engineering departments of local governments. Other users include the real estate industry, individual home owners, and geologists and seismologists involved in advisory and review services. Geotechnical consultants also use these maps in preparation for their more detailed investigations.

•The CDMG should expand its detailed mapping of fault zones in urban and urbanizing areas of the state in the next five years. The CDMG has been conducting field mapping of faults in urban and urbanizing areas of the state since 1960. At first the fault mapping developed as an adjunct to landslide mapping conducting in cooperation with local governments. In recent years the detailed fault mapping has been supported in part by grants and contracts from the U.S. Geological Survey's Earthquake Hazard Reduction Program and from local governments.

The faults or fault segments that are proposed to be mapped in detail have significant potential for future movement and are situated in locations affecting public safety. Faults that are proposed for investigation include the Whittier fault (Los Angeles and Orange Counties), the San Andreas fault from Wrightwood to Redlands (San Bernardino County), the Calaveras fault (Alameda and Contra Costa Counties), the Santa Ynez fault (Santa Barbara and Ventura Counties), and the Rodgers Creek-Healdsburg fault (Sonoma County). In addition to these onshore faults, the current program of detailed mapping of faults offshore from San Diego County should be continued and expanded to define the recency and character of faulting. Earthquakes on faults offshore from San Diego could affect this, the second largest urban center in California. Studies of the seismicity of southern California indicate that about 20 percent of the total seismic moment released in southern California may be released in the offshore regions (Anderson, 1979, p. 153). Depending upon the character of faulting in the offshore areas, local tsunamis may be generated that would have great impact on coastal developments.

•An area that needs additional study before any specific fault mapping project is proposed is the west side of the Central Valley of California from the vicinity of Kettleman Hills north to the vicinity of Lake Berryessa. This area has been the location of four magnitude 6 to 7 earthquakes in the past century and three magnitude 5.5 to 6 earthquakes in the present century, and overlies the boundary between Sierra Nevada province basement and Coast Range province basement. Locally in this area there are centers of urban development such as the Fairfield-Vacaville area and the Tracy area. If a major fault exists in this area capable of generating a significant earthquake, it could represent a significant seismic hazard to the western portions of the valley. Information on the seismicity of this area would also be helpful in assessing design of new dams along the west side of the Central Valley and for the levee system of the Delta.

Determination of Fault Activities and Earthquake Recurrences

The CDMG projects to determine the age of latest movement along faults and the frequency of occurrence of damaging earthquakes employ the use of geology, seismology, geophysics, geomorphology and soils science. Many of the projects in this section follow or are conducted in conjunction with the projects described in the preceding section.

Zoning of Active Faults (Alquist-Priolo Special Studies Zones Act)

This program includes those projects and activities conducted by the CDMG in response to the Alquist-Priolo Special Studies Zones Act of 1972 (Statutes of California, 1972).

The Alquist-Priolo Act, which was passed by the California Legislature following the San Fernando Earthquake of February 9, 1971, is intended to regulate building in designated active earthquake fault zones. The basic aim is to deter building - especially of homes in subdivisions, but also other structures for human habitation - across active faults that could tear the structures apart or undermine their foundations and footings by surface faulting or fault creep. The act specifically calls for the zoning of four known active faults (San Andreas, Calaveras, Hayward, and San Jacinto), and authorizes the State Geologist to designate others. Fault traces and the special studies zones encompassing them are delineated on 1:24,000 scale maps, preliminary maps are sent to the affected cities and counties for review, and official maps are then provided to each city and county having jurisdiction over lands within the designated regulatory zones (Scott, 1979, p. 46).

Under the Alquist-Priolo Special Studies Zones Act, the State Geologist (Chief of the CDMG) is required to delineate Special Studies Zones, compile and issue preliminary review maps and official maps, continually review new data to revise or delineate additional Special Studies Zones, and consider waiver requests by cities and counties for

approval. In addition, he must maintain a public file of geologic reports (the "special studies" required of developers of "projects" within the zone) required by cities, counties, and other permitting agencies (State of California).

The State Mining and Geology Board formulates policies and criteria to guide cities and counties, serves as Appeal Board for appeals that cannot be coped with locally, advises the State Geologist, and establishes policy for implementation of the Act (Hart, 1977, p. 3).

Cities and counties are responsible for local implementation of the Act within the delineated Special Studies Zones, approve permits for development, and collect fees for building and development permits to cover administrative costs (Hart, 1977, p. 3).

State agencies have an implied responsibility for safe siting of state structures within Special Studies Zones (Hart, 1977, p. 3).

The Seismic Safety Commission provides program advice to the CDMG relative to the Alquist-Priolo Special Studies Zones Act.

The Act applies to all land divisions on which structures for human occupancy are planned, as well as to all structures, per se, intended for human occupancy, except for single-family, wood-frame dwellings not exceeding two stories, that are planned as part of a development having no more than three such dwellings (Scott, 1979, p. 46).

The administrative policy and criteria adopted by the State Mining and Geology Board provide that no structure (with the above exception) for human occupancy shall be permitted to be placed across the tract of an active fault. Faults which have had surface displacement within Holocene time (about the last 11,000 years) are regarded as active and therefore potentially hazardous. Furthermore, the area within 50 feet of an active fault shall be assumed to be underlain by active branches of that fault unless and until proven otherwise by an appropriate geologic investigation and submission of a report by a geologist registered in California (Hart, 1977, p. 20-21).

During 1973, the first year of the program, special studies zones along the four major faults were delineated on 175 7.5-minute quadrangle maps and were officially issued on 1 July 1974. During 1974-79, faults in an additional 113 quadrangles were zoned, reviewed, and officially released. As of 1 January 1980, 288 official special studies zones maps have been issued.

During the 1974-75 fault zoning compilation efforts, it became apparent that the Division could no longer rely solely upon existing geologic information in making zoning decisions. There was a clear need for the Division to rely more heavily on its own new observations and evaluations in the field and of aerial photographs. As a result, a 10-year fault mapping and evaluation program was planned and approved in early 1976. Under this program, about 3,000 miles of potentially active faults were to be evaluated over a 10-year period on a priority basis (Figure 2). A fault evaluation report is written for each fault evaluated. Fault evaluation activities are conducted outside of the identified work areas when the need arises - for example, when an earthquake causes surface fault rupture.

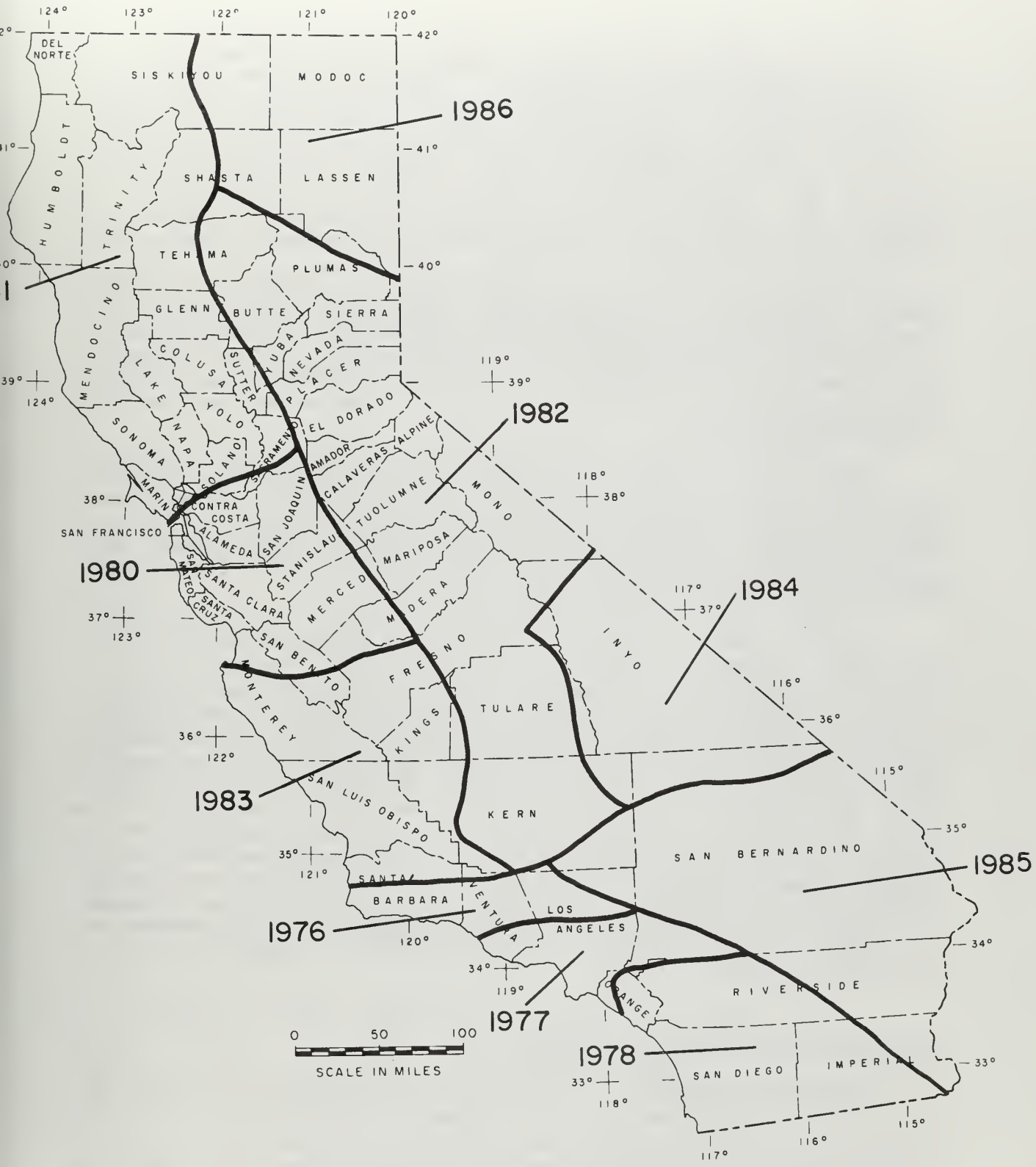


Figure 2. Fault evaluation plan (Alquist-Priolo Special Studies Zones Act) showing work plan priorities. Potentially active faults in each work area are evaluated during the year indicated, and those faults determined to be active are zoned.

•A project should be initiated to prepare a series of summary articles or data sheets on typical fault ruptures based upon the fault evaluation studies. The purpose of the project would be to systematically characterize different types of surface fault rupture for different styles and magnitude of faulting in different terrane. This would be an effective means to make the findings contained in the in-house fault evaluation reports available to others. This project should be initiated soon to take advantage of the knowledge of the authors of the Fault Evaluation Reports who are currently on the staff.

The data sheets would have maps, photographs of geomorphic features, graphs, cross-sections or trenches, and a tabulation of data (fault rupture length, sense of offset, average and maximum slip, associated seismicity, and references, with little or no text). The two to four page summaries could be published in the Division's monthly publication, California Geology; they could eventually be assembled for publication as a CDMG Special Report.

These articles or data sheets would be useful educational tools for geologists, seismologists, planners, and others. Moreover, by using a systematic format, various fault rupture and seismic events could be readily compared. Although the work would be done in part by existing project geologists, an additional geologist would be needed to keep the fault evaluation program on schedule.

•A project should be initiated to prepare a manual on the use of geomorphic features in characterizing the age of latest movement of faults; the manual would be used in evaluating potentially active faults for the Alquist-Priolo Special Studies Zones Act program. The Alquist-Priolo Act program presently depends significantly upon geomorphologic interpretation because this method lends itself to rapid evaluations, both on air photographs and on the ground. By proper use of geomorphologic techniques the more active faults can be readily distinguished from those that have little or no activity. More work needs to be done to sharpen this fault evaluation tool, to learn its limitations, and to educate others in its use. One of the uses of the proposed manual would be to train geologists newly assigned to the Alquist-Priolo Act program. It is the current practice to rotate the assignments to this program every year or two. As a result geologists in this program must be trained frequently.

Evaluation of California seismicity

California seismicity, as defined here, is a complete description of the locations, sizes, and date of occurrence of earthquakes in California and the adjoining area to a distance of about 100 km outside the state border. The CDMG California Seismicity program includes all seismology projects directed toward or contributing to a more complete understanding of the seismicity of California. This seismicity information is essential as input for the seismic risk studies described in a later section of this report.

Projects include gathering and compiling all historical and instrumental seismicity data into a single Earthquake Catalog of California, seismic monitoring of selected faults to determine their seismic activity, seismic monitoring of aftershock sequences following significant earthquakes, and studies directed toward evaluating earthquakes possibly induced by the works or activities of man.

The CDMG Earthquake Catalog of California is a computerized listing of more than 40,000 earthquakes beginning with the earliest known records in 1769. It provides a unified source for the seismicity data of the entire state covering the known historical period. It records the time, location, and size of earthquakes that had epicenters or effects in California. This information is essential for evaluating relative earthquake risk in different parts of the state (Toppozada and others, 1978, p. 1).

The post-1931 catalog data is a synthesis of the instrumental data compiled in the University of California at Berkeley (UCB) and the California Institute of Technology (CIT) earthquake catalogs with additional data from the University of Nevada at Reno and the U.S. Geological Survey. The data for the period before 1932 is based largely upon existing descriptive catalogs such as that of Townley and Allen, newspaper files, and the technical literature on seismology. The catalog provides source references of information on each of the earthquake parameters listed, such as epicentral location, magnitude, and intensity (Toppozada and others, 1978, p. 1).

Because earthquake catalogs for northern California (UCB) and for southern California (CIT) are available from 1932 to the present, the CDMG has directed its efforts primarily to analyzing and cataloging the significant earthquakes which occurred before 1932 (Toppozada and others, 1978, p. 1).

The CDMG Earthquake Catalog project was initiated in 1972. In 1978, study of the pre-1900 earthquake was partially funded by a U.S. Geological Survey grant. This grant support continued in 1979 and 1980. When the study of pre-1900 earthquakes is completed in 1981, the CDMG Earthquake Catalog of California will be the most accurate and most complete earthquake catalog for any state in the United States.

The CDMG Earthquake Catalog is being assembled, stored, and maintained as a series of data files on computer magnetic tape. The computer output is available to the public in the form of magnetic tapes, microfiche listings, printed reports covering different time intervals, and published epicenter maps.

The Earthquake Catalog project will be completed with respect to historical earthquakes during the next five years. The project will then be directed mainly to keeping the catalog current, updating the locations of the more poorly located historic earthquakes, and standardizing the quality ratings assigned to earthquake locations.

Data on current earthquakes will continue to be added to the Earthquake Catalog as received from the three principal sources of

earthquake data in California: the University of California Seismograph Stations at Berkeley, the California Institute of Technology Seismographic Laboratory, and the U.S. Geological Survey. These data will be supplemented by CDMG seismic monitoring and by earthquake data from other sources, notably the University of Nevada at Reno.

•The spacial and temporal variations of the earthquake data in the catalog should be analyzed and evaluated for use in seismic risk studies.

•The locations of selected groups of critical earthquakes in the Earthquake Catalog should be restudied using modern, precisely located earthquakes in the master event location technique. This would refine knowledge of the location and extent of seismically active areas in the state.

•The quality ratings assigned to the earthquake locations in the Earthquake Catalog should be standardized. At the present time each of the major contributors of earthquake data use their own system to characterize the quality of the data. One gives quality ratings such as "good" with no indication of the uncertainty in distance. Another gives the uncertainty rating in kilometers. The CDMG will attempt to devise a system whereby the uncertainty of the locations can be stated in a standard way for all entries.

Seismic monitoring studies along selected faults to determine their seismic activity have been limited to the frontal faults of the San Gabriel Mountains in Los Angeles and San Bernardino Counties. The initial CDMG seismic monitoring study was conducted in 1977 along the Cucamonga fault in San Bernardino County. This fault was selected because of recent U.S. Geological Survey mapping that indicates the presence of Quaternary or younger fault scarps along much of its length (Morton, 1976), because of indications of current earthquake activity on it, and because of its proximity to the Pomona Valley, a region of rapid urbanization. The results of this study indicate that several other faults in this region besides the Cucamonga fault may be active. These include the Red Hill, the San Antonio Canyon, the Walnut Creek, and possibly the San Jose faults. In addition, possible buried faults beneath the Pomona Valley that may represent seismic safety hazards to Fontana and Chino were discovered (Cramer and Harrington, 1980).

CDMG seismic monitoring studies are presently (1980) being conducted farther west in a populated urban area along the Sierra Madre fault in Los Angeles County. This is a segment of the same fault zone on which the San Fernando Earthquake of 1971 occurred. When the seismic monitoring project along this segment of the Sierra Madre fault zone is completed, other potentially active faults in urban or urbanizing areas that may be seismically active will be monitored. The criteria for selecting faults for study are proximity to urban centers and possible impact on existing or planned critical facilities.

Examples of faults that have been selected for possible study are: the Ventura fault in Ventura County, the Healdsburg-Rodgers Creek fault zone in Sonoma County, the Green Valley fault in Solano County, and the Santa Ynez fault in Santa Barbara County.

Monitoring aftershocks following selected significant earthquakes was begun in 1978. The first aftershock study was conducted following the March 1978 M 4.5 Ukiah earthquake. This earthquake was monitored to determine its relation to the Maacama fault, a segment of which lies near the U.S. Army Corps of Engineers' Warm Springs Dam project - then under CDMG review. Subsequently, seismic monitoring of aftershocks has been conducted following the Mt. Shasta earthquakes of August 1978 (M 4.6), the Lake Crowley (Bishop) earthquake of October 1979 (M 5.8), the Mammoth Lakes earthquake of September 1978 (M 4.3), the Bridgeport earthquake of October 1979 (M 6.5), and the Livermore Valley earthquake of January 1980 (M 5.8).

Insights derived from aftershock studies vary for each earthquake. The information gained from the studies include the areal extent of fault rupture, the hypocenter depth, and the attitude of the fault plane. Some of the criteria used to determine whether to conduct aftershock studies include: (1) it is a significant earthquake in a geographic area not normally covered by another agency such as the U.S. Geological Survey, the California Institute of Technology, or the University of California, Berkeley; (2) CDMG is requested to assist another agency to improve seismograph coverage; (3) the earthquake occurs in an area where a CDMG project is being conducted; or (4) the earthquake is unusual. An example of the latter was the Mt. Shasta earthquake swarm of August 1978 and the associated surface faulting. It was initially thought that this swarm of magnitude 4 earthquakes might be a precursor of a volcanic eruption (Bennett and others, 1979, p. 27).

Seismic monitoring of aftershocks following selected significant earthquakes will be continued. It is expected that of six moderate ($5 \leq M < 7$) or otherwise significant earthquakes that occur each year on the average, about two per year will merit CDMG monitoring. The monitoring may last from two weeks to several months depending on the duration of the aftershock sequence and whether the aftershocks migrate to new areas.

- The CDMG has the instrumental capability to conduct two seismic monitoring studies concurrently, but the manpower to conduct only one. Thus, after an earthquake occurs that should be monitored for aftershocks, it is necessary to cease on-going active fault monitoring in order to begin the aftershock monitoring. The CDMG needs to expand its seismic monitoring capability so that two independent networks of seismographs can be deployed concurrently. Additional trained personnel are needed to develop this capability.

Studies to evaluate earthquakes possibly triggered by the works or activities of man began in 1978 with the aftershock study of the Ukiah earthquake of March 1978. Investigation of historic water level fluctuations in Lake Mendocino and the historic seismic activity in the area has revealed an empirical relationship between changes in the lake level and seismicity (Toppozada and Cramer, 1978, p. 275).

The CDMG has conducted limited studies of seismicity, generally including field seismic monitoring, near Shasta Lake, Lake Oroville, Lake Crowley, and Bullard Bar Reservoir. At Lakes Oroville and Crowley, historic seismicity shows an empirical relationship to changes in lake levels.

•The CDMG project to evaluate the possibility of earthquakes having been induced by the works or activities of man are being conducted at a very modest level. Studies to evaluate possible reservoir-induced seismicity should be expanded. A CDMG proposal has been submitted in response to the U.S. Geological Survey's RFP-781W to conduct such a study (Toppozada and Cramer, 1980).

Cases of possible reservoir-induced seismicity (RIS) will be compared to determine their common hydrological, geological, and seismological characteristics. The post-impoundment seismicity will be compared to the earlier seismic history to determine to what extent reservoirs affect the natural seismicity. To identify the factors necessary for RIS, reservoirs exhibiting RIS will be compared to similar reservoirs having no related earthquakes. Ultimately, it may be possible to assess the likelihood of RIS at planned and existing California reservoirs.

Determination of recency of faulting and recurrence intervals of large earthquakes.

In this section are those projects dealing with the determination of the age of latest movement along faults and the frequency of large earthquake occurrences. The techniques involve the use of geology, seismology, geophysics, geomorphology and soils science. These projects generally follow those described in the section on Fault Mapping and Analysis or are conducted in conjunction with those projects.

An understanding of long-term seismicity is critical to the safe siting and design of structures and to the establishment of realistic building codes. The most important contribution that can be made to that understanding is to learn more, region by region, of the late Quaternary history of deformation (Allen, 1975, p. 1041). The distribution of earthquakes near a specific site - for example, within 25 to 50 km - is the most sensitive indicator of seismic risk for that site. Usually the historical record is too short to give an adequate indication of the frequency of seismic activity in an area this small, and it is necessary to interpret the geological record from studies of smaller regions or of specific faults to obtain fault slip rates or regional strain rates, from which estimates of the site's geological seismicity can be made (Anderson, 1979, p. 135-136).

There is a great need for a better understanding of site-specific seismicity. Realistic estimates of the likelihood and recurrence rates of large earthquakes on a local scale are crucial for the design of critical structures such as dams and nuclear facilities, as well as in the formulation of building codes that are both adequately conservative and economically realistic (Allen, 1975, p. 1041). A better understanding of the Holocene movements on the various faults is needed in order to prepare a better seismic probability map of California than now exists. It is necessary to know which faults have moved most recently, and which ones have moved most often (Allen, 1975, p. 1043).

The CDMG has been involved in recency of faulting and recurrence studies to a limited extent. These kinds of studies are logical extensions of the fault mapping activities that the CDMG has been conducting for several years.

•The CDMG should expand its studies of recency and recurrence of faulting. These studies should include detailed geologic mapping, trenching and borehole sampling, the application of various age dating techniques such as radioactive dating, soils analyses, and geomorphological studies. Studies such as these offer the best hope of inferring what has happened during earthquakes within the very recent geologic past and, in consequence, what is likely to happen again in the near future (Allen, 1975, p. 1056). The CDMG is primarily interested in studying either faults in urban and urbanizing areas or faults near which the CDMG is conducting review activities. Examples of faults that the CDMG should study include the Elsinore, the Raymond-Santa Monica, the Verdugo-Eagle Rock, the Rose Canyon, the Calaveras, and the Healdsburg-Rodgers Creek faults.

A variety of techniques are available for tackling the recurrency question, but the effectiveness of any of them depends upon how well the following requirements have been met:

(1) Detailed knowledge of the fault zone, both to understand site-specific fault geometry and precise fault trace location, and to make intelligent target choices for recurrence studies.

(2) Some form of shallow sub-surface exploration, normally either trenching or drilling.

(3) Datable material at the study site.

(4) Knowledge and experience in trench logging and soils.

Most previous recurrence interval studies have failed because one or more of the above requirements (commonly item 1) was not adequately met. Division staff have the expertise and experience through years of detailed fault studies and trench observations to address all the elements confidently except item 3. Finding datable material at the site will always remain a matter of chance. Intelligent site selection can improve the odds, but it can not guarantee success. The gamble involved in the search, however, is worth taking in light of the critical value of the information sought.

The Division should capitalize on its experience on detailed fault mapping by establishing a multi-disciplinary "recurrence interval task force" with the goal of establishing recurrence intervals on all major faults in the state which present potential seismic hazards. Initial efforts would be most effective on faults recently studied by the CDMG. Target faults should be prioritized by the task force on the basis of potential hazard and chance of success. Alquist-Priolo Act files could help direct the target selections. The principal users of this information include planners, geologists, and engineers.

High precision geodetic measurements provide the basic data necessary to enable detection and definition of crustal movements that can be used to identify "active" faults. Geodetic monitoring may be conducted on those faults that have been identified as "active" in order to identify slip rates and type of movement occurring. In addition,

analysis of geodetic data can, under some conditions, reveal evidence of concealed faults where surficial geologic data may be totally lacking or obscured by urban development.

The CDMG geodetic studies are accomplished as special projects in support of critical structures review and in support of other Division geotechnical investigations.

The CDMG geodetic studies should be directed mainly to the establishment and monitoring of detailed short-line (1 km aperature) geodetic networks across faults that have been determined to be "seismically active" by the CDMG seismic monitoring projects.

•The CDMG should initiate a project to assess the applicability of various age-dating techniques to age-date Quaternary and Holocene sediments.

The CDMG has conducted age-dating studies involving the use of coiling ratios of foraminifers, pollen analysis, and paleosol analysis. The paleosol analyses have proved to be useful for age-dating faults in the Sierra Nevada foothills, and the CDMG should similarly support other recency of faulting studies.

There are other age-dating techniques that may have promise in specific geographic areas of the state. Micromammalian fauna has proven to be very useful for age-dating purposes in some arid areas and may prove to be useful in southern California for age-dating Quaternary and Holocene sediments. This could provide an independent age-dating technique to supplement others or to use where other methods are not applicable.

The use of pollen for age-dating may be applicable in the Mojave Desert. Pollen is resistent to destruction and is widely disseminated by winds. Therefore, it may be particularly applicable in harsh climatological areas such as the Mojave Desert. If it proves applicable, a palynologic type section could be developed for age-dating use. The type section could be correlated with the numerous archaeology sites in this region.

Another age-dating technique that should be explored is the correlation of volcanic ash falls. Because of the numerous volcanic ash beds in the Quaternary and Holocene sediments of Ventura County, the correlation might be attempted there.

The CDMG seismologists should be closely involved in all recency of faulting and recurrency studies. The historical seismicity as contained in the Earthquake Catalog should be compared with the "geological seismicity" as determined by the geological studies of faults. Even though the historic record may be too short to adequately evaluate the recurrency interval of large earthquakes for particular faults, the frequency versus magnitude plots for the smaller events may be useful guides to the frequency of the larger earthquakes. This was done for the Auburn dam site review (Davis and Bacon, 1979, p. 15) and should prove useful for other faults.

Evaluation of Earthquake Potential

The evaluation of seismic risk at locations where sensitive man-made structures are planned depends critically on a correct estimate of the maximum expectable earthquake magnitude. Maximum expectable earthquake magnitudes have been estimated from fault length (Mark, 1977, p. 464), seismic moment (Smith, 1976, p. 351), and maximum expected rupture area (Wyss, 1979, p. 336). Bolt (1978, p. 235) has shown that published curves of fault rupture length versus magnitude may be quite unreliable.

The CDMG depends on estimates of maximum expectable earthquake magnitudes in many of its review functions. It is essential that the best estimates are used to provide the proper degree of seismic safety to structure designs.

•The CDMG should initiate a project to evaluate the concept of maximum expectable earthquake magnitude, the methods used to determine it, and its proper application. Geologists and seismologists need to be consistent in the usage of these terms and concepts.

The CDMG should sponsor a symposium or workshop to conduct a thorough review of the state of the art in estimating maximum expectable earthquakes. The participants would include leading seismologists as well as the engineers who design structures based on maximum expectable earthquakes. Results would also be useful as input for a revision of the CDMG maximum credible rock acceleration map (Greensfelder, 1974).

Investigation of the Earthquake Generating Mechanism

Knowledge of the earthquake generating mechanism is an important starting point for evaluating seismic risk. Earthquake source parameters such as fault rupture length, slip rate, and fault rupture area are needed to evaluate the magnitude and frequency of occurrence of earthquakes on particular faults.

•The CDMG should initiate a project to analyze and model the subsequential changes in the stress field due to successive magnitude 6 and larger earthquakes occurring on known faults in the San Francisco Bay Area during historic time. The model should incorporate the data in the Earthquake Catalog and the available geodetic strain data, and should be modified to account for the observed strain changes following successive earthquakes. The CDMG has prepared a static crustal strain model for the Transverse Ranges of California (Rodgers, 1979). The proposed Bay Area model would be an attempt to introduce a dynamic approach to the modeling by comparing changes in stress after successive earthquakes.

If the model prepared is compatible with the increased seismicity before the great San Francisco earthquake of 1906 and the ensuing quiescence, it would suggest that increased seismicity premonitory to great earthquakes is expectable in the area.

•The CDMG should initiate a project to measure earthquake source parameters such as dimension, slip, and stress drop from CDMG strong-motion records using corner frequencies. These subsurface parameters could then be compared with surface fault ruptures and other surface effects. The CDMG needs to know the earthquake source parameters in order to predict ground response. The earthquake source parameters would also be of value to other seismologists for conducting seismic risk studies. Since the CDMG has the strong-motion records, it should make as much use of them as it can to promote seismic safety.

CHARACTERIZATION OF WAVE PROPAGATION AND PREDICTION OF GROUND RESPONSE TO EARTHQUAKE SHAKING AND GROUND RUPTURE

This section of the report deals with those CDMG projects and activities directed toward study of what happens to earthquake waves between source and site, and the earthquake effects at a specific site. The major on-going CDMG projects in this section are the Strong Motion Instrumentation Program and the Orange County ground response study, supported in part by U.S. Geological Survey grants.

Crustal Modeling

In the CDMG review of the appropriateness of seismic parameters used in the design of critical facilities, questions are sometimes raised concerning possible modifications of earthquake waves by the geologic materials between the earthquake source and the site under consideration. It is sometimes contended that the earthquake motions are attenuated by the path materials. At other times it is contended that the earthquake motions are enhanced by some focusing effect or directional effect. The CDMG needs to develop the capability to evaluate these ideas.

- The CDMG should initiate a project to develop the capability to model the interaction of earthquake waves and the transmitting media.

In particular, the CDMG should evaluate the applicability of focusing effects on earthquake wave amplitude. These effects may be important to the design of critical facilities proposed to be built in the state, such as LNG terminals, dams, and power plants. This project should employ strong-motion records to help in the determination of (a) the properties of the earthquake source such as dimension, slip, and stress drop, (b) attenuation, (c) radiation and focusing, (d) local crustal structure, and (e) hypocenter location.

Estimation of Ground Motions

This section includes those projects dealing with the fault rupture process, the modification of ground motion by surficial geologic materials, and the measurement and analysis of strong earthquake motions.

Modification of ground motions by surficial geologic materials

Ground response to earthquake strong-motions vary from place to place depending to a great extent on the character and properties of the underlying geologic materials. Given the location and source parameters of an earthquake, it is possible to predict ground response when the physical properties of the site are known. The predicted ground motions at particular sites could then serve as guidelines for seismic parameters for design of structures.

The CDMG has been conducting a ground response study for the past two years in Orange County; the study is supported in part by a grant from the U.S. Geological Survey. The methodology developed in this study is generally applicable to other Quaternary basins in the state.

•The CDMG should expand its Orange County ground response study to other urban areas of the state that are underlain by Quaternary sediments. The urban areas have the large data base and the high risk potential necessary to justify the effort. Examples of basin areas meeting these criteria include the Los Angeles Basin, the Ventura-Oxnard Basin, the San Diego area, the Santa Maria area, the Santa Clara Valley, and the Petaluma-Santa Rosa Valley area.

Measurement and analysis of strong ground motions (Strong Motion Instrumentation Program)

The Strong Motion Instrumentation Program (SMIP) was established in Chapter 1152 of the Statutes of 1971, and the CDMG was designated the responsible managing agency. The objective of the program is to obtain detailed records of the ground motion response of representative soil and rock units during earthquakes, and data on the response behavior of all types of structures to those earthquake-generated ground motions. The earthquake motion data recorded by the instruments are reduced to a usable form by the CDMG. The processed results are made available to structural engineers for application to improvement of structure design for resistance to earthquake damage, thereby improving public safety and reducing property losses.

•The SMIP is a single program effort. The program can be divided into phases, some of which will have milestones rather than completions. These phases are: (a) instrument system installation, (b) instrument system maintenance, and (c) data processing.

The installation of strong-motion instruments, including phasing in digital instruments, will be approximately 45 percent complete by June 30, 1986, with 150 structures and 320 free-field sites instrumented. By the end of the instrument installation phase, which will be in the year 2020 at the currently anticipated level of funding, a total of 530 structures and 520 free-field sites will be instrumented.

SMIP currently employs a total of three field service technicians. A budget change proposal is before the legislature to add an additional technician to handle the increasing number of instruments serviced. A subsequent budget change proposal will be required in two years for the same purpose. If a budget change proposal to augment the SMIP EDP effort is successful, the central data handling system for processing strong-motion records will be fully operational by June 30, 1983, and will be expanded to meet the data processing needs until completion of the instrument installation phase projected to be in the year 2020. Users of strong-motion data will also benefit from the central data processing center (with time-sharing capabilities for direct access by appropriate users) that has been proposed for development over the coming five-year period.

•In order to meet the program objectives in the shortest possible time, the program should be accelerated the maximum amount consistent with efficient operation.

The instrument installation phase can be accelerated to a level of 50 structure and 25 free field installations per year. This would reduce the time required for instrument installation from 40 years to 10 years.

The maintenance of installed instruments will require more service technicians sooner if the instrument installation phase is accelerated.

The data handling system for processing strong-motion records will have to be expanded sooner to handle the completed instrument system if the instrument installation phase is accelerated.

The acceleration of the SMIP activities as described above would greatly improve the usefulness of strong-motion data to seismic risk mitigation studies. The greatest improvement can be provided in an acceleration in deployment of free-field instruments and conversion to digital recording equipment. Acceleration of instrument deployment to approach maximum saturation would help to ensure data acquisition in areas with limited seismographic coverage. Accelerating the deployment of instruments would also allow the systematic development of arrays designed to record data on propagation effects. Conversion to digital recording equipment will add the capability for pre-event memory and thus enable the capture of complete P wave data.

The Strong Motion Instrumentation Program can make direct contributions to crustal modeling and attenuation modeling studies. Because of the characteristics of strong-motion instruments, near-field data in unclipped, true magnitude form is recovered. Further, digital equipment with pre-event memory has the capability for recording true P wave and S wave arrival times. These capabilities facilitate precise determinations of earthquake location, focal depth, and P wave character. Further, the absence of the clipping inherent in sensitive seismographic equipment will provide data required for detailed P and S wave attenuation and P to S wave amplitude ratios studies. Carefully designed and completely instrumented arrays will be useful in source propogation studies including focusing and radiation patterns. Finally, response spectra from free-field instruments can be utilized in staff studies of source properties such as crustal depth to property interfaces.

•A project should be initiated to improve the SMIP electronics laboratory and provide a capability for instrumentation improvement to meet the state's unique needs.

The technology of structure instrumentation needs improvement and continuing study. Advancements in instrument design, particularly in the design of recorders, would increase the value of the Strong Motion Instrumentation Program to the earthquake engineering and structure design communities. The capability to make such advancements could be realized with the addition of a sophisticated electronics laboratory and a small machine shop.

Estimation of Ground Failures

This section includes projects dealing with the observation of secondary failures associated with historic earthquakes, studies to assess the potential for secondary failures to occur, and studies to correlate the patterns and dimensions of fault rupture with fault type and earthquake size.

In the past, following certain damaging earthquakes, the CDMG has assembled a special team of geologists to study various post-earthquake effects. The team has mapped, among other things, the secondary failures, mainly ground cracking and landslides, that were triggered by the earthquake shaking (Evans, 1975; Morton, 1975). These secondary failures were documented in order to alert local government officials of areas that are likely to give rise to further landsliding and mudsliding when saturated by rains and to assist in the assessment of the potential for secondary failures in other areas during future earthquakes.

•The CDMG should expand its capability to conduct studies of secondary failures, mainly landslides, following damaging earthquakes. Personnel should be trained and ready to begin work immediately following significant damaging earthquakes. The products of these studies are useful to other CDMG projects and to local government.

The CDMG currently does not have any projects in progress designed to assess the potential for secondary failures such as seismically-induced landslides. The products of such projects, for example, maps showing the location of areas prone to landsliding in the event of severe earthquake shaking, would be very useful for earthquake preparedness planning by local governments.

•The CDMG should initiate a project to evaluate the potential risk of seismically triggered landslides occurring in the urban and urbanizing portions of hillside areas. The targets of such a study include the Santa Monica Mountains, the Santa Cruz Mountains, other urbanizing areas in the Coast Ranges surrounding the greater San Francisco Bay area, and urbanizing areas in Mendocino County. Use could be made of the Orange County ground response study insofar as it is applicable to hillside areas. Information about the maximum credible earthquake that could affect the various areas should be used as input. Post-earthquake studies of secondary failures conducted by CDMG and others should also be used to guide the studies. At present there are no systematic studies of this type being conducted.

The CDMG and others have conducted post-earthquake studies to map the patterns and dimensions of fault ruptures following earthquakes that have caused surface fault rupture. A number of these studies have now been conducted for different size earthquakes and with different earthquake mechanisms. There have also been attempts to qualitatively characterize the size and type of surface fault ruptures associated with different sizes and kinds of earthquakes. A systematic study should be made to try to quantify the results and make use of this information for predictive purposes.

•The CDMG should initiate a project to analyze the geometry of fault ruptures and correlate these with type of faulting and size of earthquake. The resulting correlations may be useful for estimating fault rupture patterns for future earthquakes.

The resulting products would be useful for earthquake preparedness planning by local governments.

EARTHQUAKE PREDICTION

The CDMG is currently engaged in two activities relative to earthquake prediction. The first involves the evaluation of earthquake predictions made by others through membership in the California Earthquake Prediction Evaluation Council, and the second involves the earthquake prediction studies that the CDMG is conducting.

Membership in California Earthquake Prediction Evaluation Council

In 1974 the Office of Emergency Services established the California Earthquake Prediction Evaluation Council, composed of nine earth scientists qualified to judge the technical merit of earthquake predictions from any source. The State Geologist (Chief of the CDMG) is the Chairman and ex-officio member of the Council. The CDMG seismology program manager is also a member. The Council provides the Office of Emergency Services with professional opinion as to the validity of the technique used to arrive at a specific earthquake prediction. It is then the responsibility of the Office of Emergency Services to take appropriate action in event of a scientifically valid earthquake prediction.

CDMG participation in the California Earthquake Prediction Evaluation Council is expected to continue at the current level. The Council during the coming five years should be preparing improved earthquake prediction evaluation guidelines and procedures since the present guidelines (Gay and others, 1977, p. 158-160) were prepared before the existence of a National Earthquake Prediction Evaluation Council.

Prediction of Time, Place, and Magnitude of Earthquakes

The CDMG's involvement in earthquake prediction studies has been concentrated along a segment of the San Andreas fault extending from the vicinity of Parkfield, Monterey County, to California Valley, San Luis Obispo County (Bacon and others, 1975). The monitoring activities have included long- and short-line geodetic surveys, gravity-leveling, tiltmeter measurements, microacoustic emission studies, and telluric current studies.

The segment of the San Andreas fault extending from Middle Mountain, near Parkfield, southeast through Cholame Valley is a transition zone between two lengthy fault segments of markedly contrasting behavior. From Middle Mountain northwest to near San Juan Bautista, the seismicity of the fault is characterized by many earthquakes of magnitude 5 and lower and infrequent earthquakes with magnitudes near 6. Surface movement along this segment of the fault occurs as nearly continuous slippage or "creep." Movement occurs at an average rate of approximately 3 centimeters per year along most of this fault segment. Southeast of the transition zone along the San Andreas fault, from Cholame Valley to near

San Bernardino, there has been no evidence of fault slippage and little significant earthquake activity since the great Fort Tejon earthquake of 1857. This section of the fault has apparently been "locked" since 1857 and thus should be regarded as a likely location for the next magnitude 8+ earthquake in California.

It has been suggested that the Fort Tejon earthquake of 1857 might have begun as a moderate earthquake near Parkfield that "got away" (Kerr, 1980, p. 80). Parkfield earthquakes in the magnitude 6 range recur every 10 to 30 years. Thus, predicting the next great quake along the southern segment of the San Andreas fault may be directly related to predicting moderate earthquakes at Parkfield. The Division's monitoring projects near Parkfield are aimed at identifying earthquake precursors.

In 1959 the California Department of Water Resources began a program of periodic long-distance (15-30 km) geodimeter measurements along the San Andreas fault including the Parkfield area. Since 1969, the CDMG has continued the crustal movement measurements. Beginning in 1972, the CDMG installed tiltmeters to provide continuous surveillance of crustal deformation between Parkfield and the Carrizo Plain. In addition, in the early 1970s a precise gravity profile was established to monitor changes in elevation, three short-line crustal movement survey figures were set out using a tellurometer, and telluric current and microacoustic monitoring were commenced. Most of these activities have continued at a low level since initial installation.

CDMG earthquake prediction activities in the vicinity of Parkfield should be continued until the next moderate earthquake occurs near Parkfield. If no earthquake precursors are detected, the project should be reevaluated.

The CDMG monitoring is being conducted on an intermittent basis with six microacoustic recording stations along the San Andreas fault from Parkfield to Palmdale, and five telluric current measuring stations between Parkfield and the Carrizo Plain, a distance of 90 km. Two of the telluric stations operate full time.

•The CDMG should expand the monitoring of telluric current and microacoustic emmissions along the Parkfield segment of the San Andreas fault. The specific area that should be instrumented is in the vicinity of Middle Mountain. Four more full time telluric current stations and four more microacoustic stations, two full time and two part time, should be added.

The CDMG telluric current monitoring near Parkfield has detected possible earthquake precursors before a 1975 earthquake and before a 1976 swarm of earthquakes. The U.S. Geological Survey is not conducting any telluric current or microacoustic monitoring. The CDMG should therefore maintain its involvement with these activities in the Parkfield area and expand them modestly to increase the possibility of capturing a precursive event.

INCREASING PUBLIC SAFETY THROUGH ADVISORY SERVICES AND IMPROVED PUBLIC AWARENESS OF EARTHQUAKE HAZARD AND RISK

This section of the report includes four CDMG activities dealing essentially with advisory services and information dissemination. Advisory services are provided to a host of public decision makers who have need for the CDMG's technical input as part of their policy development process. Information dissemination of a more general nature is provided by formal and informal publications of the CDMG, by presentation of papers to scientific and lay groups, by publication of articles in professional journals, publication of the monthly magazine California Geology for a very broad audience, and responses to letter and in-person requests.

Information Dissemination

The objective of the activities in this section is to facilitate the preparation and distribution of geologic information. The CDMG information staff prepares technical presentations and news releases, answers technical letters and inquiries, and produces the monthly magazine California Geology, as well as technical information pamphlets and bulletins. Distribution of California Geology exceeds 12,000 copies monthly. It provides a vehicle for disseminating technical geologic information of current interest to a wide spectrum of readers from layman to scientist.

The publications staff drafts maps, prepares reports and maps for publication, and ensures their appropriate distribution. These publications are used by all levels of government and the public in land use planning, geologic evaluations, and construction siting. Information and publication sales desks are located at all three CDMG district offices, and an extensive technical geologic library is located at the San Francisco District Office.

The preparation and publication of CDMG's monthly magazine California Geology is a continuous and on-going activity. The magazine will continue to emphasize seismic safety, with more than half of its space allocated to the subject.

•On a regular basis, articles on the work of the CDMG that are prepared for California Geology should be submitted to newspapers in the area of interest. If the articles are not in a form suitable for press use, they should be revised so that they will be suitable.

The CDMG publications program includes all publications activities except those involving California Geology. It is estimated that 30 to 40 reports will be published per year during the five year period July 1, 1981, to June 30, 1986, and that at least 75 percent of them will address seismic safety. Therefore, as many as 150 reports dealing with seismic safety may be released during the five-year period specified.

•The CDMG should develop a program to provide CDMG staff to give talks on seismic safety at schools, colleges, and universities on request. Notices should be sent announcing the availability of the speakers and their subjects.

•The CDMG should consider the use of television and radio spot announcements as a way to get wider distribution of CDMG seismic safety information to the public.

•The CDMG should initiate the use of taped lectures and slide shows on seismic safety subjects to be made available to public groups free of charge.

•The CDMG should conduct a study to evaluate the feasibility of establishing a library of unpublished geotechnical data. A large amount of modern geologic fault investigation work is never published, not widely circulated, generally unavailable, and usually unknown. This work, produced by consulting geologists, could be a source of detailed geologic information if it were accessible. A valuable contribution to all geologists and to the state in general would be an inventoried collection of this work in a single location, with an index similar to the "Index to Geologic Maps of California" published by the CDMG as Special Report 130. Compiling such a collection would be a major undertaking, and would require a long-term commitment to maintaining and investorying these reports, but the usefulness of the collection may well justify its cost.

Assessment of Product Effectiveness

This section includes those activities designed to assess the effectiveness of CDMG publications to convey seismic safety information to the appropriate audience.

•A study needs to be made to evaluate the effectiveness of the detailed fault rupture maps the CDMG produced after the 1971 San Fernando earthquake. It would be worthwhile to look at how that data was used and what impact it had on the improvement of seismic safety.

Recommendation for Improved Seismic Safety Legislation, Codes, and Ordinances

This section contains those projects dealing with seismic safety mandates imposed by state and local governments. In recent years the Legislature has mandated that local governments and others take certain steps to improve seismic safety. The effectiveness of these statutes depends upon implementation by local government. All local governments are not equally capable of achieving the improved level of seismic safety desired. The effectiveness of legislation, codes, and ordinances pertaining to seismic safety should be reviewed and recommendations made for improvement when necessary.

•The CDMG should initiate a project to review and evaluate the effectiveness of the seismic safety elements of general plans of all local governments in the State. The CDMG is the official depository of seismic safety elements of general plans prepared by all local governments. The CDMG has no authority to require improvement of inadequate seismic safety elements. However, the CDMG should initiate a project to review the seismic safety elements of these general plans and advise local governments of any geotechnical deficiencies, to be sure that all available pertinent information has been used.

Advisory and Review Service to Federal, State and Local Government

This section includes those projects carried out by the CDMG's Advisory Services unit. Advisory activities include geologic and seismic review of: (a) hospital site reports under provisions of the Hospital Safety Act of 1973, (b) thermal power plant sites under agreement with the Energy Resources Conservation and Development Commission, (c) critical facilities sites such as dams and LNG plants, (d) environmental impact reports received through the State Clearinghouse, and (e) coastal zone development site reports under contract with the California Coastal Commission.

The CDMG's geologic and seismic review of certain critical facilities including Auburn dam, Warm Springs dam, Point Conception LNG site, San Onofre Nuclear Power Plant site, and Lawrence Livermore Laboratory site - will be completed during the five-year period July 1, 1981,to June 30, 1986. In addition, the power plant siting and outer continental shelf studies being conducted for the Coastal Commission will be completed.

It is anticipated that CDMG's responsibilities in the area of critical facilities siting will grow in the next five years. The Department of Conservation has, by requests from other State agencies and the Governor's Office, become increasingly involved in the review of power plants, liquefied natural gas (LNG) facilities, and dams. It has been recommended in a current budget change proposal to augment this capability with the services of an additional technical position to assist in these evaluations. CDMG's other review activities are expected to continue at substantially the same level as in the past.

•The CDMG should initiate a project to review the geology and seismology of all facilities that store or produce substantial amounts of radioactive material to identify those that pose potentially significant environmental and public health hazards in the event of seismic damage. In 1979, AB 3110 (Bates) was an attempt to provide legislation on this subject.

•The CDMG should initiate a project to review the geology and seismology of oil, gasoline, and natural gas pipelines that are in highly populated areas of the state, to identify any seismic hazards that might exist. Companion legislation (SB 1663, Petris, and AB 1042, Bates) introduced in 1979-80 would require the State Fire Marshal to adopt regulations and to certify reactivated intrastate pipelines for flammable

or combustible liquids. Those bills would seek seismic safety advice from the Seismic Safety Commission, but the proposed CDMG project would be a more appropriate and comprehensive answer to the need.

•The CDMG should initiate a study to evaluate whether or not a seismically safe site for the disposal of radioactive wastes exists in California. Each state may be required to have its own disposal site - at least for low level radioactive wastes. These disposal sites are needed immediately to prevent unsafe disposal of these wastes. Although evaluating the "safety" of a possible disposal site is an extremely complex undertaking, and seismic safety is only one, and possibly not the most important, of the many considerations that would be involved in the evaluation, it is clear that it is an important consideration and that the CDMG has a role to play in the process.

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